Sustainable Product Life Cycle

Ayushi Bansal[1], Sunita Kumar [2]
[2] Assistant Professor
[1, 2] Rajasthan Institute of Engineering and Technology, Jaipur - [RIET]

Abstract- *The concept of creating sustainable product life cycles highlights the significance of a comprehensive, long-term planning and management strategy to maximize product benefit throughout the product's life cycle.*

Product life cycle thinking is a philosophy that helps producers create successful products. The book offers numerous life cycle management techniques and tools and combines them into a comprehensive planning strategy.

The top academic life cycle management experts in Europe have consolidated their knowledge in this monograph. Readers will get knowledge of various life cycle modeling methods and instruments as well as digital information assistance. Using consistent product data management and closed-loop information cycles, manufacturers may unlock the hidden performance potential of their goods and production lines, as demonstrated by industrial examples.

Keywords- Sustainability, Product Lifecycle Management, Green Manufacturing, Product Development.

I. INTRODUCTION

The most pressing problems facing modern society are environmental ones, like global warming and energy usage. Modern businesses must take sustainability into account while developing new products. Environmental restrictions have evolved as a result of the rising scarcity of resources and raw materials, possibly having profound effects on logistics and production.

It is widely agreed in both business and academia that sustainability must be implemented early in a product's life cycle. Unfortunately, quality and cost concerns still dominate the present product development operations in manufacturing organizations. These businesses are concerned that incorporating environmentally friendly practices into their product development plans will increase costs and hurt their ability to compete. It is not shocking that environmental requirements are frequently given secondary consideration.

Elkington36 stated that the idea of sustainability should include societal, economic, and environmental considerations. The triple bottom line is another name for this idea, which takes into account profit, the environment, and people all at once . As a result, the scope of sustainable design encompasses entire product lifecycles.

Sustainable design is typically the process of creating a product that fulfills its purpose effectively, makes money for the business, is acceptable to society, consumes the least amount of resources, and doesn't create any hazardous waste.

To execute sustainable development in a business, the appropriate sustainability tools and practices must be used. They are essential in helping developers make decisions that are environmentally sustainable.

However, studies have shown that many practical sustainability indicators and approaches are exceedingly complicated and alien to most workers and, frequently, management as well. The fact that there is no "one size fits all" approach and that stand-alone procedures are frequently deceptive and may lack the technical depth required to accurately assess progress makes the situation worse. This makes them more difficult to understand and apply.

II. CLASSIFICATION FRAMEWORK

The objective of this study is to systematically gather, assess, and synthesize prior research on sustainable product design. Our goal is to examine the principles behind and limits inherited by each method, as well as to highlight the types of sustainable methods that have been used in their different design phases.

For the purpose of categorizing these research and contrasting their features, we suggest a two-dimensional framework.

A framework for categorizing various initiatives in sustainable design is presented in this section. The two metrics in this paradigm are.

Members of the product development team can find clear general operational guidelines along the ordinate in Guideline. Metrics are straightforward qualitative and quantitative standards for environmental evaluations.

This study is focused on viewpoints connected to sustainability such as manufacturing, environmental, disassembly, and recycling. DfX stands for Design for X perspectives. LC Costing refers to methods for calculating life cycle costs.

Last but not least, Methodology approaches sustainable design concerns from a methodical perspective that takes into account the interdependencies among diverse stakeholders in product development.

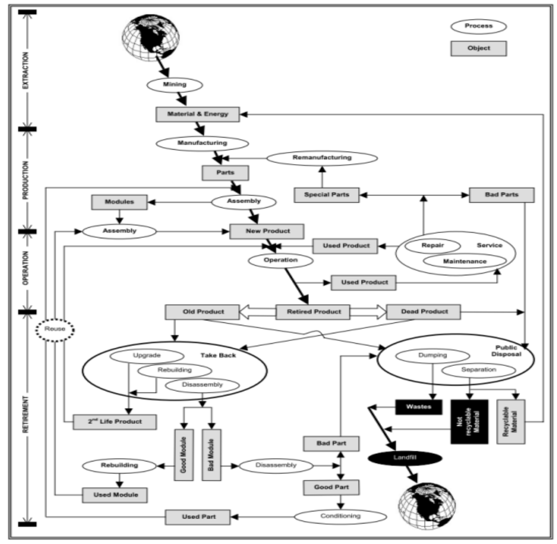
The timeline for a typical product design process is indicated by the abscissa. Problem definition, conceptualization, preliminary design, and detail design are the general classifications for such a process (Ogot & Kremer, 2004;40 Ulrich & Eppinger, 2004;41 Pahl & Beitz, 199642).

Customer needs and product functionality are identified at the problem definition stage.

The product architecture, system-level design, requirements, and component selection are all created during the conceptualization phase. Components, associated motions, and form are displayed at the preliminary design stage, also known as embodiment design.

The physical prototype is finalized during the design phase together with the precise process and material requirements. The framework shown below serves as a structural classification of the studied sustainable design initiatives.

The reviewed sustainable design efforts are structurally categorized into the framework below:



III. LITERATURE REVIEW

3.1 Guideline

In order to encourage design for sustainability in design education and practise, Spangenberg et al.21 utilised the SCALES (Skills, Creating change agents, Awareness, Learning together, Ethical obligations, and Synergy and co-creating) principles. SCALES principles' overarching objective is to satisfy customers while using fewer resources. This objective can be further broken down into the efficiency of satisfaction, supply/use, product, production, and provision.

Waage27 proposed a "roadmap" based on guidelines to integrate the sustainability conflicts between economic, social, and environmental issues. Four phases make up the road map.

Phase 1 sets an environment for sustainability that may generate concerns about customer and product sustainability. Through mapping and sustainability research.

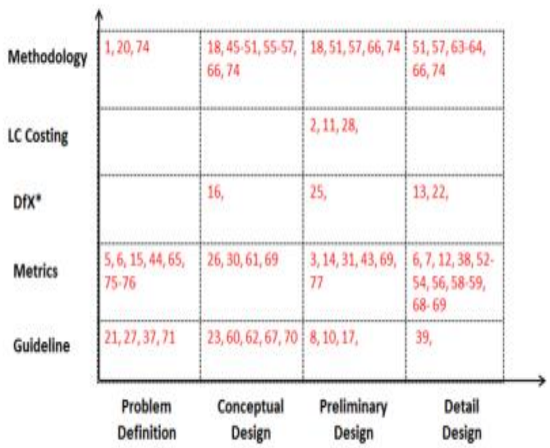
Phase 2's sustainability challenges are identified.

Phase 3 evaluates and takes into account potential future directions in relation to a desired sustainable outcome.

Phase 4 is the final stage, where you take action, get input, launch a product or service that is focused on sustainability, evaluate it, and (re)review it in light of the context and concept of sustainability. By posing sustainability-related queries to designers, the entire sustainable design process is accomplished.

A reference information system for sustainable design was created by Santana et al. The life cycle evaluation, product service systems, social, and economic factors are all covered by this programme. During the product life cycle, there are six steps in the reference process:

conception of functionality, the procurement of raw materials, production, trading, delivery, usage, maintenance, and reuse, recycling, energy recovery, and disposal.



Most recently, Bovea and Pérez-Belis67 reviewed and categorised technologies created to assess environmental requirements for products and to make it easier to include such requirements into the product design process. Their primary objective is to offer designers a manual for choosing the eco-design tool that is most appropriate for a given case study. A taxonomy framework was created based on criteria including

(1) the strategy used for the environmental assessment
(2) the product requirements that must be integrated in addition to the environmental one (multi-criteria approach), and
(3) whether the tool has a life cycle view.

The stages of the design process where the tool can be used, whether they are qualitative or quantitative, and whether the tool has been used on a case study are the other four factors.

3.2 Metrics

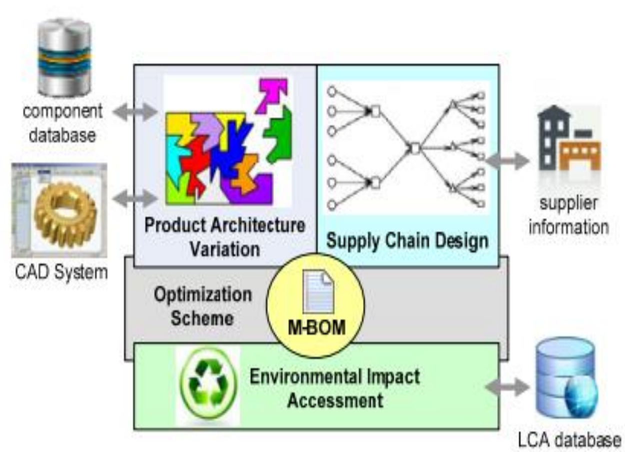
A metric-based strategy for appreciating tools for various design aims was offered by Fargnoli and Kimura5. Six criteria are used to evaluate various Quality Function Deployment (QFD) based, LCA, and checklist tools: the ability to accurately define the product's requirements/performances, usability, effectiveness of the method in assessing the environmental performances of the product, ability to provide new solutions, possibility to review the design activities allowing designers to perform a proper design management, and ability of the method in fitting into existing processes. As a result, appropriate methods can be used for various products and situations.

An innovative redesign strategy that incorporates QFD, LCA, life cycle costs (LCC), and contingent valuation (CV) is proposed by Bovea and Wang44. This method identifies choices for environmental improvement while comparing the increase in product life cycle cost caused by these options to the extra cost that customers are ready to pay in exchange for realizing environmental advantages.

A case study on the redesign of office furniture demonstrates that it is feasible to redesign items without sacrificing other client criteria in order to significantly increase their sustainability. In product eco-design, determining customer willingness to pay (WTP) is essential.

Due to the necessity to gather the necessary product data, LCA analysis requires both time and resources. Thus, a full LCA might be performed primarily to evaluate a product's environmental impact. The goal of simplified life cycle assessment (SLCA) methodologies is to make LCA more usable during the initial design phases.

When not all product data is available and fixed, it is difficult to do an environmental assessment for the entire life cycle during the design process. As a result, it's critical to assess simplified procedures, as well as the information they demand and the kinds of outcomes they might generate.



They suggested using indicator-based approaches for eco-design and claimed that LCA also requires indicators because it is still unclear how many connections exist between causes and subsequent environmental impacts. In order to allow users to produce missing evaluation data based on multiple available sources, the indicator-based Oil Point Method (OPM) was created.

Product-related primary energy consumption is used by the OPM presented in this research as a gauge of the severity of environmental effects. Case studies of actual products show how the method's effectiveness in assisting designers in conducting "quick-and-easy" overviews of their design choices. The aforementioned techniques are used throughout the detail design stage.

3.3 DfX

A methodology was proposed by Luh et al.16 that uses a generic modularized product architecture to identify the development of green products. The product family, product model, option control, and physical component level are the four tiers that make up this methodology.

Green design can be seen as another option in the Product Data Management (PDM) by mapping the modules and option items. The PDM programme "TeamCenter" is used to present a case study on the LCD TV product line. Customers with various green requirements could use this strategy to find an answer. Green product creation is therefore possible at the conceptual design stage.

Green design principles were used by Tabone et al.22 while choosing materials. Each principle acts as an indicator, and each indicator has a ranking. As a result, sustainable design ideas are provided. The detail design step is where the aforementioned two methods13,22 start.

To create sustainable product designs, Vinodh and Rajanayagam25 used CAD and Design for Manufacturing (DFM) concepts. The total energy used for material extraction, manufacture, use, and end-of-life calculations as well as carbon footprint, water eutrophication, air acidification, and other metrics will all be calculated by this software. This approach begins with the preliminary design phase.

3.4 Life Cycle Costing

Bevilacqua et al.2 assessed the environmental impact of circuit board design using LCA methodology as well as financial considerations.

Economic and environmental break even points are supplied as supporting data for decision-makers based on the ratio of reduced energy dissipation. The Life Cycle Sustainability Assessment (LCSA), which condenses environmental LCA, LCC, and Social LCA, was presented by Kloepffer11 as a new direction.

3.5 Methodology

Sustainable factors into each stage of the design process. It prompted designers to take sustainability into account as a component of the design process at every stage. Although this methodology can spot sustainability problems in the early stages of design, it didn't offer any recommendations when several components of the indicators were at odds.

A sustainable product conceptualization system (SPCS) is suggested by Yan et al. First, domain specialists create the product platform for a particular product using approaches such as design knowledge hierarchy (DKH) and generic sorting. Morphological configuration can be used to generate preliminary design possibilities.

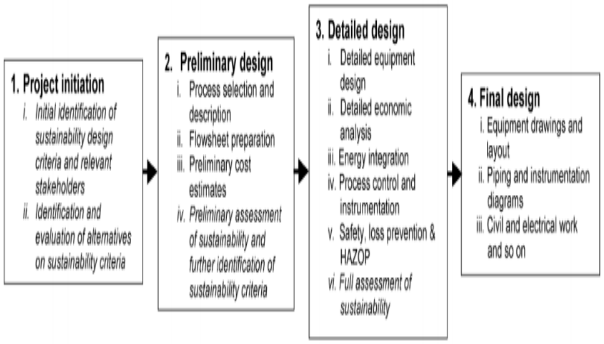
The initial design space is then reduced using the Hopfield network based on design criteria requested by subject matter experts. utilising the graded sustainability and cost criteria requested by domain experts utilising repertory grids, the sustainability and cost pairings can be obtained for choosing environmentally friendly design solutions.

An example of a cell phone design case study demonstrates how the system functions.

Product architecture, which is generally decided upon during the system design phase, has a significant impact on the entire product lifecycle and has been recognised as the key element connecting product design and supply chain activities for environmental decision-making.

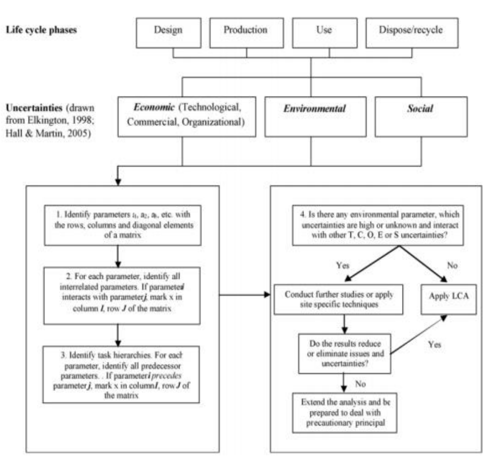
One of the earliest attempts to lessen a product's negative environmental effects using computer-aided design of the product structure was Feldmann et al.'s study48. In order to analyse product structure with relation to a complicated product's end-of-life behaviour, a computational framework was created.

Using multi-attribute value theory, this approach calculates an overall score for environmental effect while taking metrics related to the quantity of materials used, the materials used in the product, the product's disassembly, and the product's capacity to be recycled into account for different product structures. Product designers might use the findings to determine the economically.



A grounded theory-based methodology was created by Matos and Hall18 to study problems while incorporating sustainable development into the supply chain. All stakeholders should provide Economic (which can be broken down into technological, commercial, and organisational aspects), Societal, and Environmental (ESE) parameters related to their job functions in all phases of the product life cycle, as shown in Figure 6 below, in order to address the uncertainties and complexities in the supply chain network. These parameters serve as the input for a design structure matrix, which identifies the interdependencies between each parameter.According to the case study, a supply chain network is more sustainable the less dependent its ESE characteristics are on one another. These techniques begin with the preliminary design stage.

Gaha et al.'s64 attention was directed at enhancing sustainability during the detail design stage. They suggested combining CAD and LCA to create a straightforward eco-design tool. In order to build the product that corresponds to the model, the geometric properties of a CAD model are examined in order to estimate their environmental influences during the phases of raw material extraction, manufacture, usage, end of life, and transportation.



IV. FINDINGS AND DISCUSSION

We can draw general conclusions from our assessment of the literature.

The following are also discussed along with each finding's ramifications and possible future study lines:

The findings of the literature research indicate that metrics-based approaches make up a larger share of sustainable design methodologies. It might be difficult to get usable metrics from life cycle assessments that are compatible with the product design process. Data gathering for life cycle inventories and a trustworthy database of materials and processes present the biggest challenges.

The life cycle effect is currently calculated using LCA tools and methods without accounting for data source uncertainties. Uncertainties still exist on how to adopt sustainable design. Two crucial efforts are necessary to address uncertainty in sustainable design: (1) quantifying the imprecision in the life cycle data inventory in the appropriate metric forms; and (2) developing reliable design methodologies based on these metrics.

Therefore, it is desirable and a more natural method for design engineers to incorporate sustainable design in CAD software. Integration of CAD with LCA is inefficient and troublesome, according to prior studies. LCA calls for more data, which CAD systems are unable to accommodate, on processes, machines, purchasing, and suppliers. Feature modeling is the foundation of the majority of CAD technology.

However, it might not be viable to correlate design elements with life cycle inventory data.

The majority of feature-based sustainable design approaches have oversimplification issues because they don't completely take into account the other stages of a product's life cycle. Environmental effects are mostly evaluated through a product's features, whereas a feature is the culmination of purposeful design (form).

V. CONCLUSION

Today's world faces a major challenge: reducing environmental consequences. Governmental rules and social initiatives have urged firms to make efforts to improve their sustainability. The production of sustainable products has become crucial for contemporary businesses. Practitioners and academics agree that choices taken early in a product's life cycle have a significant impact on raising the sustainability of that product.

To classify those studies, a two-dimensional framework with two metrics was suggested. In the ordinate, we set them apart from guidelines, metrics, designs for X, LC costing, and methodology.

Throughout the product design process, from problem definition, conceptualization, preliminary design, and detail design, each method can be used in various phases. Discussions were held about the concepts and restrictions of the best approaches in each area. The outcome provides crucial understandings for the study of sustainable design.
All of the works focused on how early design choices might minimise the environmental effects brought on by later activities in a product's life cycle.

Approaches based on metrics make up a growing share of design methodologies. Life cycle assessment metrics that are useful must take into account uncertainty inherited from previous LCA data as well as the product design process.

CAD and life cycle inventory integration is still inefficient and troublesome. LCA data pertaining to processes, machinery, buying, and suppliers is not supported by CAD systems. Environmental impacts are calculated from a process standpoint, while feature-based modelling reflects the ultimate manifestation of design intent.

A growing requirement is to create a methodical approach that can integrate the spheres of the product, process, system, and ecosystem while reconciling opposing viewpoints on product creation.

The vast majority of the studies under examination were carried out in industrialised nations. However, developing and growing nations, which use a significant amount of resources and energy, are crucial players in the world supply chain. It is critical that nations work together to develop sustainable products.

Small and medium-sized businesses (SME) should be the focus of further studies on sustainability.

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